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Characteristics of fruits and seeds of *Cereus* plants (Cactaceae) grown in South and Northeastern Brazil

Abstract

The physical and physiological characteristics of fruits and seeds were analyzed so that parameters may be determined to differentiate cactus plants of the *Cereus* genus from south and northeastern Brazil. Length, width, bark thickness, pulp diameter, weight of fruits, and sugar content (°Brix) of the fruit pulp, number of seeds (NS), weight of 100 seeds (P_{100}) and germination taxa (%G) of the seeds from plants of the two regions were evaluated. Fruit length, bark thickness and Brix degree were higher in *Cereus* plants from Maringá (south) than in plants from Picos (northeast), whilst the P_{100} of plants cultivated in Picos was higher than the P_{100} of plants grown in Maringá. NS and %G, at 30°C, were not significantly different in the seeds of the plants cultivated in Maringá and Picos. Positive Pearson correlation was reported between NS and the fruits´ weight, length, width, and diameter. Fruit width had a positive correlation with the weight, length, diameter, bark thickness and sugar content. The length, diameter and thickness of the bark were also positively correlated with the fruits´ sugar content. Above evidences suggest that larger fruits present higher Brix degree. The present study was important to shown that the *Cereus* plants from Maringá may be a source of bigger and sweeter fruits, essential characteristics for breeding programs..

Keywords: cactus, mandacaru, fruit length, bark thickness, fruit weight, weight of seeds, germination rate

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Introduction

Some studies have revealed the importance of the cactus species *Cereus peruvianus* Mill. as a fruit-crop in Israel.[1–3]A program of domestication and selection of plants of *C. peruvianus* initiated in the 90's of the last century led to the current production of the fruits that have been commercialized mainly in Israel with the name "Koubo".[4] Orchard of *C. peruvianus* in Qetura (southern Arava Valley, Israel) was originally established with seeds collected from various private garden in Southern California. Years later, seeds of *C. jamacaru* collected from the semi-arid zones of Brazil, known there by the local name mandacaru, were introduced in semi-arid ecozones in Israel[3,5] and crosses between the two species showed that the two can pollinate each other and produce viable seedlings.[5]

Crosses between the two species is not necessarily an indication that the two are the same species. However, the compatibility between plants from different regions is an important strategy for breeding programs. Species characteristics, genetics and breeding, propagation and fruits development, ripening and postharvest behavior were reported by Mizhari.[4]

Molecular analysis of various genotypes by Gutman et al.[5] showed that *C. peruvianus* species has a narrow genetic base and that additional germplasms are required for further efficient fruit improvement. Additional germplasms from *Cereus* species from south and northeast Brazil may be an alternative to expand the genetic base of the breeding program in Qetura.The *C. jamacaru* species represents a wild natural resource in the semiarid region of northeastern Brazil that has been mainly used as forage for ruminants, such as dairy cattle, sheep,[6] goats[7,8] and calves.[9] Medicinal importance has also been attributed to *C. jamacaru* since the phenolic and alkaloid compounds extracted from the plant cladodes are related to antioxidant activity and may act on the cell cycle of the tumor cells, both *in vitro* and *in vivo*, with anticancer effects and tumor reduction.[10] While the *C. jamacaru* species represents a wild natural resource in the semiarid region of northeastern Brazil, the *C. peruvianus* referred as synonym to *C. hildmannianus*[11] is extensively used as ornamental plants in home gardens and public parks and squares. Further, an industrial and economic importance has been attributed to the *C. peruvianus* in south Brazil. In fact, *C. peruvianus* plants are used for the extraction of gum used in cosmetic and food industries[12] and for the retrieval of complex heteropolysaccharides used in purification processes for industrial waste water.[13] Medicinal importance is also attributed to *C. peruvianus*. Arabinogalactan, extracted from the gum, has been indicated for the treatment of gastric ulcers.[14]

The economic importance of *C. jamacaru* plants in Brazil´s northeastern region has stimulated studies to assess the viability, chemical composition and potential for seed germination of the species.[15–20] However, there are no reports of studies with fruits and seeds of the *C. peruvianus* species cultivated in south Brazil; only the effect of different temperatures on seeds germination was reported by Bevilaqua et al.[18] The objective of the current study was to verify if fruits and seeds of *Cereus* from a location in the northeast and a location in the south regions of Brazil present promising characteristics for programs of breeding.

Materials and methods

Fruits of *Cereus* were collected from six and three plants cultivated in South (Maringá, PR, Brazil) and Northeastern (Picos, PI, Brazil), respectively. The mature fruits were collected in plants found in public parks, home gardens, and open fields in urban areas. The primary source of each plant is unknown since the vegetative propagation is the predominant form of multiplication for the species of *Cereus*, but there is a great chance of they have been propagated from different plants (inference made from different place of collect and personal information). Nine fruits, representing the northeastern region (3 fruits/plant), were collected in Picos (07º04'37"S; 41º28'01"W) and thirty (4-10 fruits/plant), representing the south region, were collected in Maringá (23°25'38"S; 51°56'15"W). The soil of the region in Picos is clayey with litholics and quartz sand and characterizes Cerrado/Savanah vegetation. The climate is characterized as tropical semiarid and hot, with maximum temperature 39°C, minimum temperature 22°C, and an average annual temperature of 30°C. Rains are scarce and the driest period occurs throughout seven to eight months. The soil of the region in Maringá consists of dystrophic red Latosol, with

subtropical temperate climate. Mean annual temperature is 21.95°C; minimum temperature is 10.3°C; and maximum temperature is 33.6°C. Rainfall rate is at its minimum in March, June, July and August and at its maximum in November, December and January, with a mean annual rainfall of 1,500 mm. Mean relative humidity is 66%.

Length, width, bark thickness, pulp diameter, weight and the sugar content (°Brix; one-degree Brix is 1.0 g of sucrose in 100 g of solution) were evaluated in the fruits of the plants from the two regions. A digital caliper was used to measure fruits´ length, width, bark thickness and pulp diameter. A refractometer was employed to measure °Brix (soon after collection). After the measurement of the fruits, the seeds were excised out of the mature fruit and washed in tap and distilled water to remove any remaining mucilage. Seeds were then surface sterilized with 10% sodium hypochlorite for 5 min and washed in distilled water. After drying at room temperature, the seeds of each fruit were counted to estimate the number of seeds per fruit (NS). One hundred seeds of each fruit were weighed in an analytical balance (Shimadzu AUY 220) to estimate weight of 100 seeds (P_{100}).

Seed germination was done following Bevilaqua et al.[18] Seeds were first soaked in sterilized water for 24 h according to recommendations by Carvalho et al.[21] distributed on two sheets of Germitest® type paper moistened with distilled water and packed in plastic Petri dishes.[18] Twenty seeds per plastic Petri dish were used in replicates, with five replicates of seeds obtained from fruits of Maringá and from fruits of Picos, totaling 100 seeds from each region. The experiment was carried out in a germination chamber at 30°C, using a 16h-photoperiod. Germination counts were taken daily, with final counts after 10 days. Seed with an emerged radicle was considered germinated.

Statistical software R[22] was employed to test whether length, width, bark thickness, pulp diameter, weight and sugar content (°Brix) of the pulp in the fruits, and NS, P_{100}, and germination taxa (%G) of the seeds from plants of the two regions were significantly different.

Results and discussion

Characteristics of the *Cereus* fruits of plants grown in Maringá and Picos

Fruit length, bark thickness and °Brix were higher in *Cereus* plants from Maringá (south) than in plants from Picos (northeast), while fruit width, diameter and weight were not significantly different for the two regions (Table 1). In spite of the greater length and thickness of the bark of the fruits from Maringá, the weight of the fruits was not greater than the weight of the fruits from Picos. The fruit length of Picos varied from 59.6 to 123 mm, with an average 83.6 mm, similar to the average described by Abud et al.[23] for fruits of *C. jamacaru* (82.36 ±5.78 mm in length). Mean weight of the Picos fruits in current study (153 g) was also similar to the fruit weight reported by Abud et al. [23] for fruits of *C. jamacaru* (154.66 ± 40.01 g). On the other hand, the diameter of the fruits from Picos evaluated in current study (42.8 g) was smaller than the diameter described for fruits of *C. jamacaru* 62.63 ± 6.63mm[23]

Table 1 Variance analysis of fruit width (FWi), fruit diameter (FØ), bark thickness (BT), fruit length (FL), sugar content (°Brix) and fruit weight (FWe) evaluated in fruits of plants of the genus *Cereus* (Cactaceae) cultivated in south (Maringá, PR) and in northeastern (Picos, PI) Brazil

Parameters	FWi Maringá	Picos	FØ Maringá	Picos	BT Maringá	Picos	FL Maringá	Picos	°Brix Maringá	Picos	FWe Maringá	Picos
minimum	37.9	43	31	33.3	3	3.1	66	59.6	8.1	6.1	45.4	62.2
maximum	80	78.2	72	64.8	10	6.32	126	123	17.1	10.8	400	344
[1] $\hat{\mu}$	60.9a	57.0a	47.9a	42.8a	6.33a	5.06b	98.2a	83.6b	12.6a	8.84b	199a	153a
[2] $\hat{\sigma}^2$	147NS	198NS	133NS	131NS	2.92NS	1.14NS	209NS	469NS	6.33NS	2.39NS	6200NS	10705NS
$\hat{\sigma}$	12.12	14.07	11.53	11.44	1.7	1.06	14.45	21.65	2.51	1.54	78.74	103.46
[3]W	0.04468	0.1855	0.752	0.189	0.5177	0.2544	0.2145	0.993	0.7406	0.2737	0.03329	0.4788

[1]Equal horizontal letters do not differ statistically from one another by t test at 5% probability. [2] * or [NS] by F test at 5% probability. [3]Statistic calculated by the Shapiro-Wilks test.

Variation in °Brix (8.1 - 17.1) and mean value (12.6) were higher in *Cereus* fruits cultivated in Maringá than in fruits cultivated in Picos (Table 2). The maximum value of °Brix observed in fruits from Picos (10.8) is similar to the mean value for *C. jamacaru.* Silva et al.[24] has reported mean rate of 10.13 °Brix for fruit pulp of *C. jamacaru*. Although few studies on fruits of the *Cereus* species have been reported in the literature to date, the high variability found in the characteristics of the fruits of the two localities (Maringá and Picos) may be a promising prospect for programs of conservation, domestication and breeding of the *Cereus* species reported by our study.

Table 2 Analysis of variance of number of seeds (Ns), weight of 100 seeds (P_{100}) and percentage of germination (%G) evaluated in seeds of plants of the genus *Cereus* (Cactaceae) cultivated in south (Maringá, PR) and northeastern (Picos, PI) Brazil

	Ns		P100 (g)		Germination (%)	
Parameters	Maringá	Picos	Maringá	Picos	Maringá	Picos
Minimum	65	140	0.196	0.234	67	71.7
Maximum	2775	1878	0.446	0.494	97	98
[1] $\hat{\mu}$	1383a	803a	0.301b	0.366a	81.6a	84.5a
[2] $\hat{\sigma}^2$	690265NS	496941NS	0.00396NS	0.00602NS	71.8NS	88.0NS
$\hat{\sigma}$	830.82	704.94	0.06	0.07	8.47	9.38
[3]W	0.1075	0.5	0.6427	0.08393	0.4763	0.3496

[1]Equal horizontal letters do not differ statistically from one another by t test at 5% probability. [2] * or NS by F test at 5% probability. [3]Statistic calculated by Shapiro-Wilks test.

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Number, weight and germination rate of *Cereus* seeds grown in Maringá and Picos

The number of seeds and the germination rate at 30°C were not significantly different in the seeds of the plants cultivated in Maringá and Picos (Table 2) while the weight of 100 seeds (P_{100}) of the plants cultivated in Picos was higher than the P_{100} of the plants grown in Maringá. Heavier seeds in cacti have been associated with cultivated plants. Rojas-Aréchiga et al.[25] evaluated the weight and the germination rate of seeds of cultivated and wild populations of the columnar species *Stenocereus stellatus* and found that seed weight and germination rate were higher in cultivated populations. Researchers suggested that human intervention for the cultivation of this species has favored seed vigor and germination capacity in the cultivated plants. Although the germination rate was not different in the Maringá and Picos seeds, the higher weight of the Picos seeds may be due to a more intensive cultivation of *C. jamacaru* plants, which has been mainly used for forage to ruminants, such as dairy cattle[6] and calves.[9]

On the other hand, significant differences in seed weights from the Picos and Maringá (lower P_{100} values detected in seeds of Maringá) indicate smaller seed size. As seed size may be a parameter to differentiate species, the smaller size of the seeds in fruits collected from plants in Maringá may indicate the occurrence of different species of *Cereus* in the two Brazilian states, according to the premise of our study: *C. jamacaru* in northeastern Brazil and the *C. peruvianus* synonym of *C. hildmannianus* in south Brazil.

The relationship between seed mass with germination rate has not been observed in 17 cacti species (*Cereus hankeanus, Cleistocactus baumannii, Echinopsis aurea, E. leucanta, E. candicans, E. spiniflora, Gymnocalycium bruchii, G. capillense, G. castellanosii, G. monvillei, G. mostii, G. quehlianum, G. schickendantzii, G. stellatum, Harrisia pomanensis, Parody mammulosa* and *Stetsonia coryne*) of seven different genera from the central region of Argentina.[26] These researchers only observed that the heavier seed generated larger seedlings.

Although there is evidence in another species of cactus (*Gymnocalycium monvillei)* that the characteristics of the germination differ according to the distribution of the plants at different altitudes,[27] differences in the germination rates of the seeds of *Cereus* plants Maringá and Picos were not detected in current study nor were they observed in a study by Bevilaqua et al.[18] No significant differences were observed, at 25°C and 30°C, in the germination rate of the seeds of the two regions. Over a period of four days, the germination rate of seeds maintained at 30°C was greater than the germination rate of seeds maintained at 25°C. However, after 8 days, temperatures 25°C and 30°C were equally effective for the germination of the plants from Maringá and Picos. Temperatures 25 and 30°C were also the most appropriate conditions for the germination of *Cereus jamacaru* seeds described by Alencar et al.[17] Guedes et al.[16] and Meiado et al.[28] reported that the optimal temperature for germination of *C. jamacaru* seeds was 30°C, whereas studies by Alencar et al.[17] showed that the germination of *C. jamacaru* seeds was higher 20°C and 25°C. Evidence that 25°C is an adequate temperature for the germination of *C. jamacaru* seeds contradicts the observation that temperatures below 30°C were not adequate for the germination of *C. jamacaru* seeds[16]. Abud et al.[23] also revealed that the highest percentage of germination in *C. jamacaru* seeds (89%) occurred at 25°C.

In current study, maximum germination rate of *Cereus* plants from Picos reached 98%, close to rates by Meiado et al.[28] for *C. jamacaru* seeds (95.8%) and for *in vitro* germination of *C. jamacaru* (92.6%) seeds described by Correia et al.[29] A lower germination rate for *Cereus* seeds from Picos (85.3%) was reported by Bevilaqua et al.[18] However, the above was not considered significantly different from the seed germination rate of Maringá (92.7%).

Pearson correlation coefficients for fruits´ and seeds´ characteristics of *Cereus* plants from Picos and Maringá

Pearson correlation coefficients for the characteristics of the fruits and seeds of *Cereus* plants grown in Maringá and Picos are shown in Table 3. A positive correlation was observed between the number of seeds and the weight, length, width, and diameter of the fruits. Fruit width showed positive correlation with weight, length, diameter, bark thickness and sugar content (°Brix). The bark´s length, diameter and thickness were also positively correlated with the fruits´ °Brix. Evidences suggest that larger fruits present higher sugar content.

Table 3 Pearson correlation coefficients for the characteristics of the seeds and fruits: number of seeds (Ns), weight of 100 seeds (P_{100}) and percentage of germination (%G) in seeds, and fruit width (FWi), fruit diameter (FØ), bark thickness (BT), fruit length (FL), sugar content (°Brix) and fruit weight (FWe) evaluated in plants of the genus *Cereus* (Cactaceae) cultivated in south (Maringá, PR) and in northeastern (Picos, PI) Brazil

Variables	Pearson coefficients	p-value
Ns x P100	-0.61134509**	0.0000356
Ns x FWi	0.66144713**	0.000004529
Ns x FØ	0.56876478**	0.00015817
Ns x BT	0.22077467NS	0.1768192
Ns x FL	0.71616692**	2.957202 ×10-7
Ns x Brix	0.24875232NS	0.1267532
Ns x FWe	0.74003444**	7.296901×10-8
Ns x %G	0.07156310NS	0.665068
P100 x FWi	-0.28669681NS	0.07680627
P100x FØ	-0.18903039NS	0.2491101
P100x BT	-0.15959592NS	0.3318032
P100x FL	-0.41985961NS	0.007792421
P100x Brix	-0.11308070NS	0.4930814
P100x FWe	-0.29584063NS	0.06746141
P100x %G	0.02417807NS	0.883842
LF x FØ	0.87866382**	1.94×10-13
LF x BT	0.32429196*	0.04399803
LF x FL	0.48181346*	0.001898259
LF x Brix	0.33100901*	0.03955928
LF x FWe	0.82336789**	1.233469×10-10
LF x %G	-0.16792242NS	0.3068591
ØF x BT	0.23001892NS	0.1589233
ØF x FL	0.43261245NS	0.005948716
ØF x Brix	0.49161340*	0.001481061
ØF x FWe	0.81067458**	3.970411×10-10
ØF x %G	-0.27744705NS	0.087259
EC x FL	0.13458895NS	0.4139925
EC x Brix	0.35152467*	0.02820567
EC x FWe	0.20658211NS	0.207023
EC x %G	0.04540868NS	0.7837063
CF x Brix	0.37825535*	0.01758137
CF x FWe	0.79874865**	1.102813×10-9
CF x %G	0.07868946NS	0.6339557
PF x %G	-0.09967921NS	0.5460099
Brix x FWe	0.44458674NS	0.004573569
Brix x %G	-0.15229045NS	0.354693

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On the other hand, seed weight and germination rate failed to correlate with fruit characteristics. Evidences that fruit and seed characteristics do not influence seed germination were also described in other species of cacti (*Aylostera narvaecensis*, *A. buiningiana*, *Rebutia kupperiana* var. *spiniflorum*, and *R. donaldiana*) by Mihalte et al.[30]

Among the characteristics of seeds (NS, P_{100}, and %G) and fruits (length, width, diameter, bark thickness, weight and °Brix) of *Cereus* from Maringá and Picos analyzed in the present study, the P_{100}, length of fruits, bark thickness and °Brix may be recommended to discriminate plants from the two regions: P_{100} rate was higher in Picos, while fruit length, bark thickness and °Brix were higher in the fruits from Maringá. The polymorphism of the lipase-5 locus[18] and polymorphisms of DNA fragments obtained with restriction enzymes and amplified by polymerase chain reaction (AFLP)[31] also indicated low genetic identity and high genetic divergence, respectively, between the Maringá and Picos plants, while the simple sequence repeats loci of DNA (SSR loci)[32] indicated moderate genetic divergence. Consequently, the analysis of morphological and physiological characteristics of fruits and seeds, plus biochemical and molecular characteristics of *Cereus* plants cultivated in Maringá and Picos, demonstrated that only 46% of these characteristics may discriminate plants from the two contrasting regions of south and northeastern Brazil.

Although few characteristics may be employed to distinguish and/or specify plants of *Cereus* from south and northeastern Brazil, current analysis was important to verify that the plants of Maringá may be source of bigger and sweeter fruits, essential characteristics for the breeding program of *Cereus peruvianus* as fruit crop in Israel which has a program of domestication and selection of plants of *C. peruvianus* initiated in the 90's of the last century and is interested in introducing material from Brazil.

Conclusion

The weight of 100 seeds (P_{100}), fruit length, bark thickness and °Brix may be recommended to discriminate plants from Maringá (south Brazil) and Picos (northeast Brazil): P_{100} was higher in Picos, whereas fruit length, bark thickness and °Brix were higher in fruits from Maringá. Therefore, plants from Maringá may be source of bigger and sweeter fruits, essential characteristics for the breeding program of *Cereus peruvianus.*

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Conflicts of interest

Authors declare no conflict of interest exists.

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